HEAT TRANSFER ANALYSIS OF BLAST FURNACE STAVE COOLER

M.Tech. Thesis Submitted to
National Institute of Technology, Rourkela

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Rourkela,2014

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Under the guidance of

(Prof . S . K. SAHOO)

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CERTIFICATE

This is to certify that the thesis entitled, "**HEAT TRANSFER ANALYSIS OF BLAST FURNACE STAVE COOLER**" submitted by **Sameer Kumar Behera** in partial fulfillment of the requirement for the award of the degree of Master of Technology Degree in Mechanical Engineering with specialization in Thermal Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

Prof.S.K.SAHOO
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Place:NIT Rourkela

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ABSTRACT

Furnace cooling technology is very important for the metallurgical industry as it cansignificantly increase productivity and campaign life of furnaces. A heat transfer mathematical model of a BF staves cooler has been developed and verified by the experiments. The temperature and heat dissipated by stave cooler will be calculated by using ANSYS®. The results has corroborated with experimental model used in RSP Blast Furnace.

In this work heat transfer analysis has been done at different temperatures (loads) from 573k to 1723k in order to compare which material of staves has given better results than the other, also nitrogen has used in stave coolers of a Blast Furnace in the place of water for cooling purposes.

Keyword:-Stave cooler,Blast Furnace cooling,Lining cooling **.**

LIST OF FIGURE

Description

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Description

Nomenclature

K Thermal Conductivity of material, (W/mK)
C_p Specific heat of fluid, J/kgK
L Total length of stave, m
A Area of stave,m^2
m Mass flow rate ,(Kg/s)
q" Heat flux experienced at hot face of stave, (w/m^2)
Q Heat extracted by the stave ,(w)
dT Temperature difference (K)
Re Reynolds number
D Diameter of cooling pipe,(m)

Greek symbols

μ Daynamic viscosity,(Ns/m^2)
ρ Density of fluid and solid,(kg/m^2)
υ Kinematic viscosity,(m^2/s)
ϕ Rayleigh Dissipation Funtion

CONTENT

CHAPTER 1

1 INTRODUCTION

A stave is a cooling device having one or more coil,which is used to cool the refractory lining. It is installed in numbers on the inner surface of a blast furnace to protect its steel shell and maintain the inner profile but copper staves have been installed in blast furnaces in the zones exposed to the highest thermal loads,Thrmeal laod of stack to belly shown Fig.1.1.In blast furnace lots amount of heat is generate because of combustion, hence lining cooling by stave technology is one of the products of such efforts.It prevent from the overheating and subsequent burn through. In Cooling system Water is used as a medium for removes the excess heat generated in the blast furnace which keep the lining cooled & prevent it from faster wearing out. Cooling system thus prevent the increase of the shell and lining temperature. Various methods exist for cooling of the shell for the blast furnace**.** The staves were made conventionally of cast iron. But now days copper staves are used in place of cast iron staves, which is excellent in heat conductivity and heat flux to the copper staves is 50% lower than that to cast iron staves. Cast iron staves are proven cooling elements that are capable of multiple campaign life in areas of the blast furnace which do not experience extreme heat loads. Copper staves are proving to be an effective and reliable blast furnace cooling element that are subject to virtually no wear and are projected to have a longer campaign service life in the areas of highest thermal load in the blast furnace.

Now a days , cooling boxes of different size, number and design were used for transferring heat of the furnace to a cooling medium in conjunction with spray cooling. Blast furnaces with cast iron cooling staves are operating since 19 century. Cast iron stave cooling was originally a Soviet discovery from where it travelled initially to India and Japan. By 1970, cast iron cooling staves have attained world wide acceptance. Since the introduction of these cast iron stave coolers, the development work of blast furnace cooling got accelerated and today a wide variety of coolers are available for the internal cooling of the furnace shell to suit extreme condition of stress in a modern large high performance blast furnace.

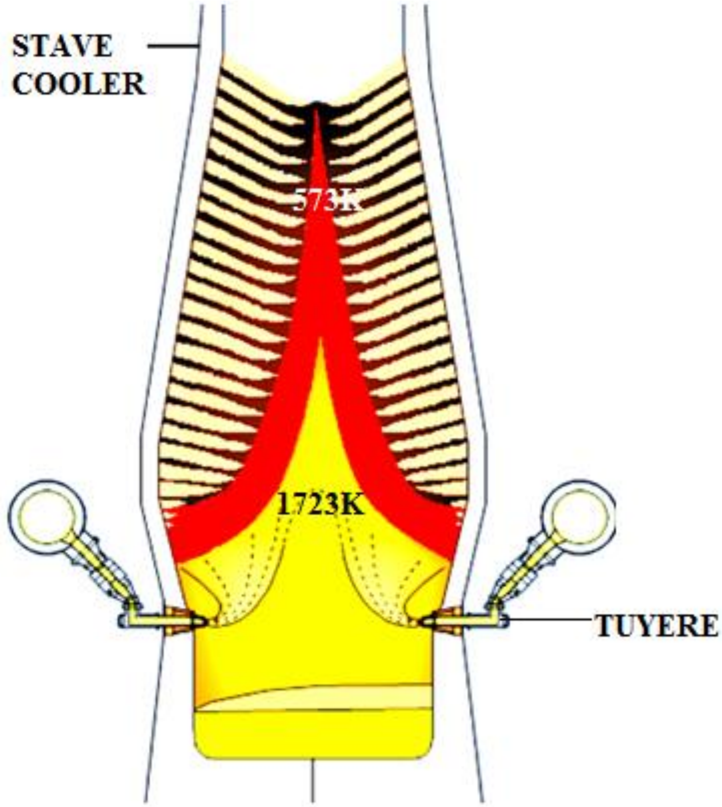

Figure 1.1 Thermal Zone of Blast Furnace

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1.1Types of Cooler

1.1.1 Plate cooler

In Europe plate cooler has been used in all large furnace. Plate coolers are generally made by either welded or cast in electrolytic copper. The usual plate sizes are 500 - 1000 mm long, 400 - 800 mm wide and approximately 75 mm high,which is shown in below Fig.1.2 . Plate cooler has kept in the zones with high heat loads of blast furnace especially in the bosh and lower stack areas,arrangement of plate cooler shown in below Fig.1.3 and 1.4.Copper flat coolers have a greater uniformity of material properties over the complete cooling element. These coolers are designed to maintain high water velocities throughout the cooler, thus have an even and high heat transfer coefficient. The copper flat plate coolers generally have multiple channels with one or two independent chambers. One of the designs of capper flat plate cooler has six pass with single chamber. These coolers are mostly welded to the blast furnace shell to ensure gas tight sealing Minimum losses of water pressure are ensured in both the piping and the element itself The figure of a commoncopper flat plate cooler design.

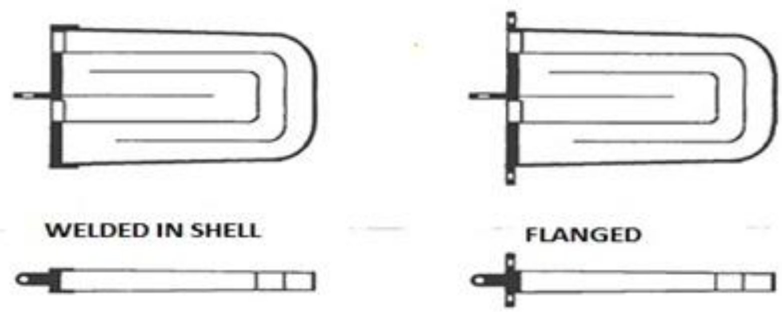

Figure 1.2plate cooler

Figure 1.3 Setup of Plate cooler in Rourkela Steel Plant(RSP)

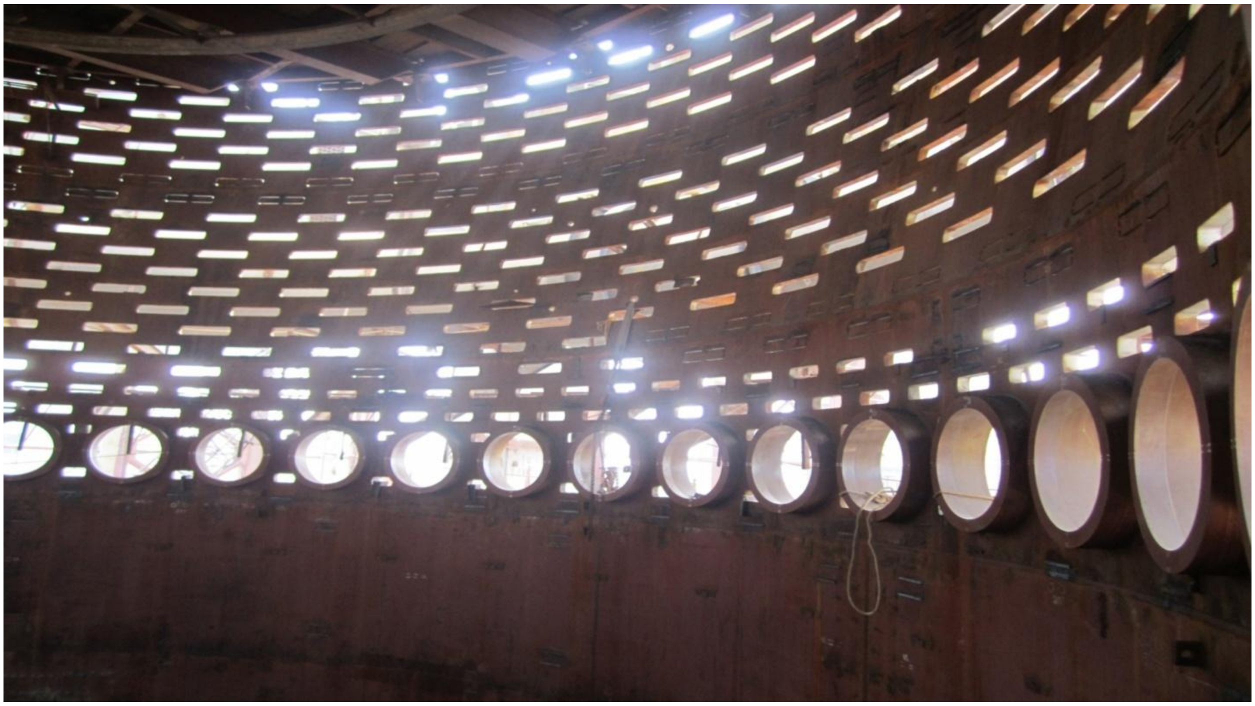

Figure 1.4 Inner view of plate cooler

1.1.2 Cigar cooler

For special blast furnace applications, Cigar Coolers can be either cast or fabricated in many different dimensions or lengths,the design of Cigar cooler shown in below Fig.1.5 . These are also called as copper jackets. Cigar coolers are used in between the plate coolers when more intensive cooling is required or there is more spacing of the flat plate coolers,which is shown in Fig.1.6. These are also used forimprovements to the existing cooling system during a campaign.Cigar cooler is generally machined by solid copper bar to form a cylindrical core and a single channel is added by drilling and plugging. Cigar coolers are normally kept on the centerlines between adjacent flat plate coolers on a horizontal and vertical plane. For the basis of installation of a cigar cooler normally a cylindrical hole is drilled through the furnace shell and existing refractory lining with a core drill.The cigar cooler use increases the cooling system area and prevents the refractory lining to chemical and mechanical attack mechanism.

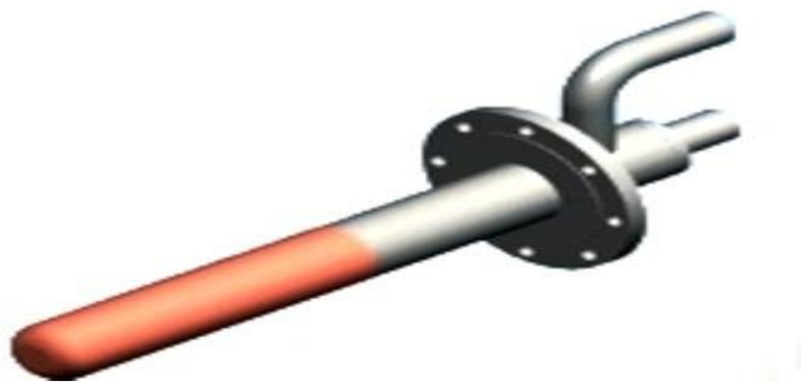

Figure 1.5 Cigar cooler

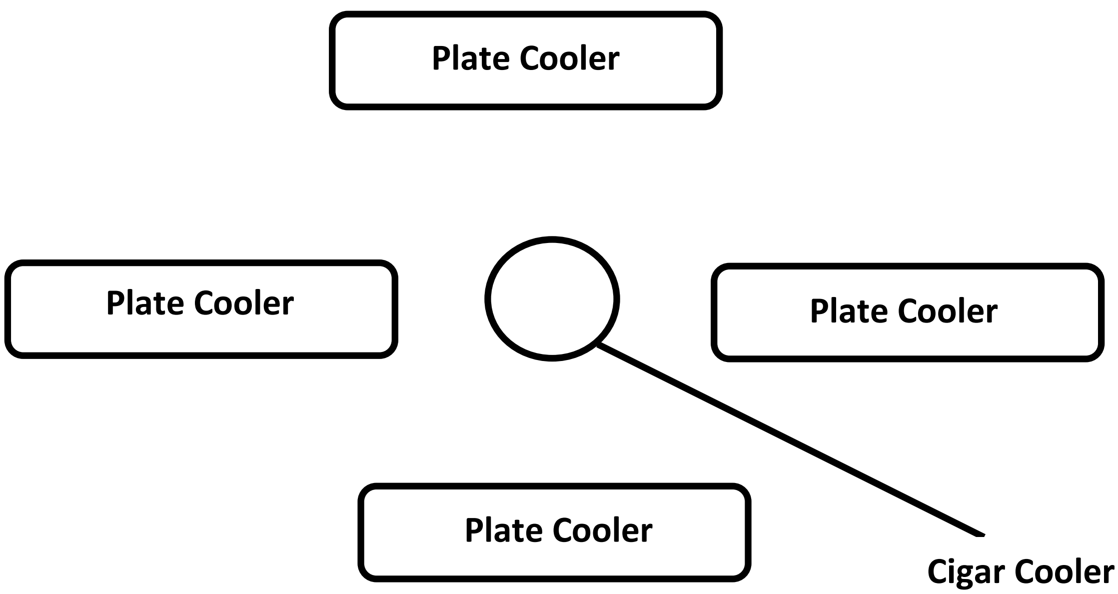

Figure 1.6 Arrangment of Cigar Cooler

1.1.3 Stave cooler

Copper staves were developed by Japan and Germany in the mid 1990s but the greater number of the installations is in or after 2000.Dimension of copper stave are 1640mm,900mm and 200mm length, breath and height respectively.Typical design of stave cooler shown in below Fig.1.7.Copper stave are use in the region of bosh, belly and lower stack to cope with high heat loads and large fluctuations of temperatures. Stave cooler of Japan are cast copper staves, but German copper staves are rolled copper plates having close outer tolerances and with drilling done for cooling passages. Drilled and plugged copper staves are normally designed for four water pipes in a straight line at the top and four water pipes in a straight line at the bottom. Internal pipe coils made by monel, copper or steel.

1.1.3.1Types of stave cooler

Smooth Surface stave cooler -Ithaving good thermal conductivity and simple structure the hot face is smooth face. It is mainly used in the front of tuyere and inner lining of BF hearth cooling.

Common Brick stave cooler-it ismostly used in bosh, belly and middle and lower part of stack. Brick inlaid is high alumina brick, silicon carbide brick and etc. hot face of this kind of stave is spacing lined refractory brick.

Common Ramming stave cooler-The hot face of stave is spacing lined dove tail with crushing refractory materials inside, and is mainly used in bosh, belly and middle and lower part of stack.

Complete Cover Brick stave cooler- stave is completely covered by bricks with thin or non lining structure to enlarge the furnace volume. It is mainly used in bosh, belly and stack.

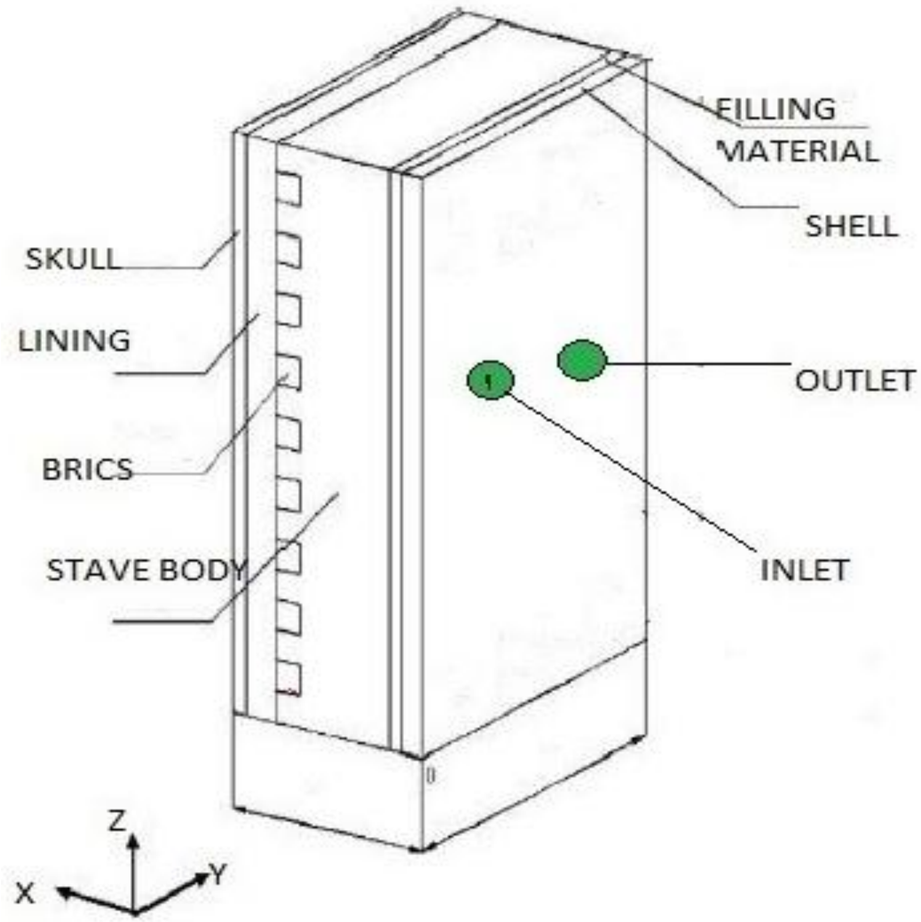

Figure 1.7 Stave cooler with lining

1.2 Colling Process of Blast Furnace

Water is come from high level tank of plant to the stave cooler at high velocity due to gravitational force. These stave cooler are designed in a closed loop rather than the conventional open systems. This allows the pipe work to be chemically cleaned, and by controlling water chemistry throughout the campaign this clean surface can be maintained, thus ensuring maximum heat transfer. The main function of the cooling system of blast furnace is to cool the furnace shell and prevent it from overheating and subsequent burn through. To accomplish this, the cooling system must be able to take up the excess heat generated by the furnace and loaded onto the shell. This heat will lift the shell and lining temperature too high if the cooling system is not effective in dispelling it. Over the years, the development of cooling systems has received a great deal of attention, especially in the last two decades. Two main competitors emerged for shell cooling, with still no clear advantage evident. The first of these is the so called cooling boxes, or sometimes better known as flat plate coolers. The second is the cast iron staves, which receive great attention especially in Japan. Where flat plate coolers, as the name describes, are flat plates that are arranged horizontally into the furnace shell, staves can be described as flat plates stacked parallel and flush to the inside of the shell and are cooled by a built in piping arrangement.

1.3 Objective of Present Work

1.To analyze the behavior of stave material at different loads

2. Design a Three Dimentional Model stave cooler .

3.To determine Temperature difference from Exeperiment

4. The Numrical results is corroborate with experimental model used in Rourkela steel plant Blast Furnace.

5.Nitrogen is use in the place of water for cooling.

CHAPTER 2

2 LITERATURE REVIEW

Y. KO et al. [1]have analyzed the Thermal Behavior in Tap-Hole Area. They found that the thermal properties of mud-core, cast able and brick and the convection heat transfer coefficient of spool have a significant effect on the tap-hole area temperature distribution they developed hearth model, which can predict the trend of thermal behavior by adjusting material thermal properties and they found temperature distribution of the tap-hole area.

Akash Shrivastava and R.L. Himte [2] – have studied stave cooler of blast furnace using heat transfer analysis. They had used two different types of skullin the lining material of the cooling stave in a blast furnace as well as two different types of bricks is considered, in which the first they had taken imperceptible thickness and the other had taken certain thickness, which is considered in millimeter (mm), so, with these two different type skulls, the heat transfer analysis did at different gas temperatures loads from 773k to 1573k they found that lining is better than other for heat extraction.

Anil Kumar et al. [3] have modeled three dimensional blast furnace cooling stave and this analysis he has taken two different types of lining material i.e. high alumina brick and silicon carbide brick . These lining materials are used at different gas temperature from 773 K to 1573 K as well as stave with skull is used at this gas temperature. They has chosen water temperature 303 K. They found that thermal stress and maximum temperature of hot face are lowest in alumina brick and highest in silicon carbide brick and. so he got silicon carbide brick is better for lining.

W.Lijun et al.[4] have analyzed three dimensional model stave of blast furnace using ANSYS. They found that reducing the temperature of water and increasing thevelocity of water would be uneconomical. They controlledthermal stress and maximum temperature in the stave by properly adjusting operating conditions of the blast furnace, operating conditions are the coating layer, gas flow, lining material and cooling channel inter-distance and gas clearance and

Diameter.

W. Zhou et al. [5]have studied on the hot face of blast furnace stave cooler. They have used two equivalent convection coefficients between gas flow and inlaid brick, and gas flow and stave body. They found that equivalent convection coefficient increased the accuracy of heat transfer numerical calculation.

W.Lijun et al.[6] have studied on intelligent monitoring methodology based on the mathematical model of blast furnace stave and developed intelligent simulation technique this intelligent simulation model of cast steel stave cooler is based on correction factor of parameters obtained by training the samples of test data of the cast steel cooling stave. They found that the data of intelligent simulation model is nearly consistent with that of experiment.

K. Verscheure et al.[7] have adopted new technology for furnace cooling in pyrometallurgical Processes. furnace cooling is very important for blast furnace, which is a key of increasing related to the pyrometallurgical industry as it can fundamental increase productivity, process intensities, and campaign life of furnaces. They also imposed a variety of problems mainly related to sustainability of the operations, safety, heat losses and .They found different cooling designs used in the non-ferrous, ferrous and alloying industries and aspects of furnace monitoring, materials selection, manufacturing, , water quality and installation when using water cooled refractory.

U. Pückoff and CH. Knoche[8] have employed various techniques cool the shell of the blast furnace bosh, belly and stack are .In earlier times, cooling boxes of varying design, number and size were used exclusively for the transferring of the waste heat of the furnace to a cooling medium ,mainly in conjunction with external cooling ,whereas during the 1970s, cast iron plate coolers, so-called staves, have attained worldwide importance for furnace cooling . The plates which have a considerable area and which are traversed by a cooling medium form an almost gap-free internal cooling of the furnace shell. Since the introduction of these staves, originally a Soviet discovery, there has been no shortage of development work, they adapted cast and cooling pipe materials, together with the overall plate construction and installation to the extreme conditions of stress in a modern large high-performance blast furnace.

S. J. GD ULA et al.[9]have found a method for determine the steady state temperature distribution in thehearth of blast furnace and the bottom is given. Various cooling and lining systems were considered. A method of solutions, coupling is applied. A fairly good agreement of computed and measured results is obtained.

C . PengYeh et al. [10]have studied about Lining erosion, which is the most important factor for identifying the campaign life of a blast furnace and developed a conjugate heat transfer model, including the heat transfer of the stave cooler and sensor bar in thermal conduction and radiation transmission and convection heat transfer in cooling pipe of stave cooler in the steady state process. They have done simulations, which are target specifically on the effects of the gas temperature, thickness of the stave cooler, slag layer thickness, material and sensor bar diameter.

They found that the refractory lining and the slag shell provide significant protection for the stave cooler body. The residual lining thickness of the cooling stave can measure by copper sensor bar. To estimate a optimum stave thickness, diameter and material of the sensor bar, were analyzed in this study.

C.M. Chang et al. [11]have developed a computational model and solved the three dimensional and Navier-Stokes equation combined with the transport energy equations and species with haet transfer physical dissolution source using the finite control volume method subjected to the segregated iterate under boundary conditions. The results analyzed the erosion of carbon bricks in the hearth of blast furnace with the different operating conditions, including the status of production of liquid iron, dead-man, carbon concentration at the inlet, and porosity distribution in quake zone during the tapping process at steady state. The results has used to diminish the erosion caused by mass transfer, and save the life of the blast furnace.

Maria Swartling [12]has focused on hearth of the blast furnace for determined, how much flow of heat in hearth of blast furnace, which part of blast furnace is exposed to high temperatures. she has done experimentally as well as numerically by heat transfer modeling. Measurements of outer surface temperatures in the bottom part of a production blast furnace were carried out. In the experimental study, relations were established between lining temperatures and outer surface temperatures. These relations were used as boundary conditions in a mathematical model, in which the profiles of temperature in the hearth lining are determined. She found that the corner between the wall and the bottom is the most delicate part of the hearth and the predictions shown that no studied part of the lining had an inner temperature higher than the critical temperature i.e.1150°C, where the molten metal of iron can be in contact with the lining.

D. Roldan et al. [13] have developed A new methodology in this research that integrates the one-dimensional heat transfer model with the three dimensional CFD model to predict hearth erosion and inner profiles. The one-dimensional heat transfer model estimates the refractory and skull thicknesses locally based on the thermocouple data and hot face temperature calculated by the CFD model. The three-dimensional CFD model calculates the velocities and temperatures of the hot metal, as well as temperatures in the refractories and skulls based on the inner profile estimated by the one-dimensional heat transfer model. An iteration procedure had developed to do perform the calculations efficiently and accurately.

G. X. WANG et al.[14] have developed a mathematical model, and solution technique for model by the finite element method, after that they did a simulation of the lower stack region of a blast furnace, with the wall consisting of crisscrossing refractory and water-cooling device. The approach is validated by the good agreement between the computed and measured radial temperature distributions, and subsequently used to study the heat transfer process under various water-cooling and blast furnace operating conditions. They found that the heat transfer and the wear process in wall of the furnace can be controlled by properly adjusting blast furnace operating conditions, such as the supply of cooling water and the gas flow rate of the blast furnace.

Jan Torrkulla and Henrik Saxen [15] have designed a numerical model for the evaluation of erosion and skull profiles of hearth in the blast furnace. This numerical model is based on thermocouple measurements,which is measure the temperature in the hearth bottom and wall lining, and evaluation the most severe erosion of the lining experienced during the campaign and also the thickness of the skull. The model is illustrated on process data from two Finnish blast furnaces. compatible measurements and calculations are used to verify the results, they found suggestions on how to control the state of the furnace hearth.

Kuncan Zheng et al.[16] -Lining erosion is one of the key factors affecting the campaign life of the blast furnace. They have studied refractory erosion of a blast furnace. They improved refractory using CFD analysis. They found that the 3-D model may realize the prediction and control of the lining erosion, but need not measure the temperature of the lining.

S.B. Kuang et al.[17]- They have numerical studied of multiphase flow, heat and mass transfer in a BF by a process model. It is then used to study The effects of hot charge operation at different temperatures. They found that the results are analyzed in detail with respect to Blast Furnace flow and performance. It is shown that compared to the conventional operation, hot charge operation can lead to an increased productivity, decreased coke rate and CO2 emission, and at the same time, increased gas pressure and top gas temperature. These effects vary, with hot charge temperature.

A Computational Fluid Dynamics (CFD) model has developed by **Dong Fu et al.[18]** to simulate the multiphase reacting flow in the blast furnace shaft. The model proposed to consider the layer structure of the burden is to solve the conservation equations for the gas and burden phase in the cell system with the type of cell prescribed.they had concluded that on one hand, each steady state case reflects the quasi steady state distribution for gas phase under that specify layer structure. In addition, each steady state case also predicts the global blast furnace performance, such as top gas composition, pressure drop and coke rate due to the number of layers in a blast furnace is large. On the other hand, the descending cycle of the layer is considered by the averaging of multiple cases with different layer structure in one charging cycle.

Cheng Su-sen et al.[19]- have designed a copper stave cooler with furnace wall in China. And developed a monitoring program for copper staves cooler with blast furnace wall , which can be used to calculate the online temperature and accretion thickness of hot surface of copper staves cooler after obtaining the values of Thermocouples of copper staves cooler . The accretion state obtained in the actual analysis has verified that the result of the monitoring program.. The monitoring program shows that the accretion would easily fluctuate when the accretion layer is extremely thick or thin, thereby the stable and smooth operation of the blast furnace is hindered. they optimized the operation of blast furnace and build up its production and found Approximately thickness (30-50 mm) of accretion layer is maintained on the wall of Shougang blast furnace.

Xie Ning-qiang , ang Cheng Shu-sen[20]- have studied the variation of gas temperature on stave cooler and displacement distributions and temperature Stress of stave cooler. when the gas temperature increased in inner side of the blast furnace from 1000 to 1600 ^{0}C. They found that that the temperature field on the cold side of cooling pipes is under control and hardly changes,. The temperature gradient near to hot sides is greater than those in other regions and the latter can reach 100 ^{0}C/ s. The stress intensity near about 400 MPa in the middle area of hot surface . The edge of the stave cooler is bent to the cold side.

S.J. Zhang et al. [21]- They have studied the behavior of solids flow in a 2D blast furnace (BF) this study was based on numerically. They demonstrated that the loss of mass strongly affects the solids flow pattern and deadman profile in a Blast Furnace.

Z. Qian et al.[22]- have developed a heat transfer mathematical model of cast steel stave cooler of Blast Furnace and examined by thermal state experiment. Calculation of cooling stave working under steady state carried out based on the model. They determined the thickness of the cooling water pipes of stave and gas clearance between the pipes and main body because, which are difficult to find by manually measurement.

2.1 Summary

From the study of above journal,most of paper found that design parameter of stave cooler and cooling coil using simulation and analysed the stave cooler at different thermal load from stack to belly position for calculate the critical temperature of hot surface of blast furnace stave and temperature difference of water in a stave cooler.In these paper did not studied about alternative medium for cool the refractory lining and has not taken any other material except copper and cast iron for design stave cooler.

CHAPTER 3

3 THREE DIMENTIONAL MODELING OF BLAST FURNACE STAVE

The biggest thermal zone of the blast furnace is concentrated within the lowerstave region of the blast furnace. Cooling stave bring in major maintenance and repair of a blast furnace. Hence ,cooling stave life is a key parameter for the life of the blast furnace. The body of the blast furnace is made of steel and cooling stave is made of cast steel. Cast steel is used because cast steel are like high thermal conductivity, specific elongation, melting temperature ,tensile strength.

3.1 Model of Blast Furnace cooling stave

Cooling staves situated against the internal face of theshell between this latter and the refractory coating fulfill a double function. The staves aremade of copper, steel, cast iron elements having a one coil or group of tubes in which the cooling fluid like a water or nitrogen circulates. The cooling fluid, in the prior art, is a water or nitrogen, and it is subjected to a vaporizationupon contact with the heat flux which the stave cooler is to be extract.

3.2 Computational modeling of cooling stave

The main objective of the study is to analyze the behavior of stave material at different loads using the heat transfer analysis by ANSYS® [13].The above three dimentional cooling stave has to be modeled by constructing a model that has been modeled in the Workbench, the dimention of stave cooler and cooling coil shown in table 3.1 and 3.2 respectfully. After that the model has to be export in .AGDB file. after that the 3-D model imported in theMeshing package,In meshing given name of face and created interface wall in between coil of stave and body of stave after that the model has to be export in .MSH file.Then .MSH file import in a FLUENT.In this package boundary condition, material selection, assumptions of stave has given,the table 3.3 shown property of material. In the below Figure 3.1is the cooling stave, there are two holes as shown in the Fig.3.2, represent the cooling pipes, inlet and outlet.

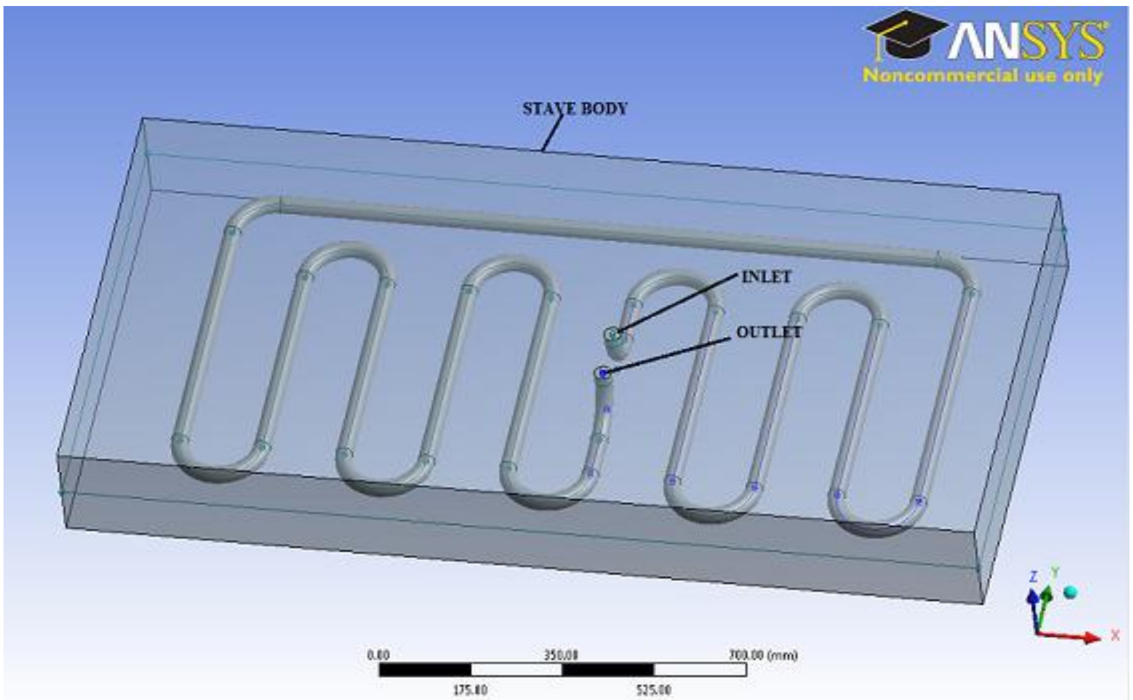

Figure 3.1 Three Dimentional Stave cooler of Blast Furnace

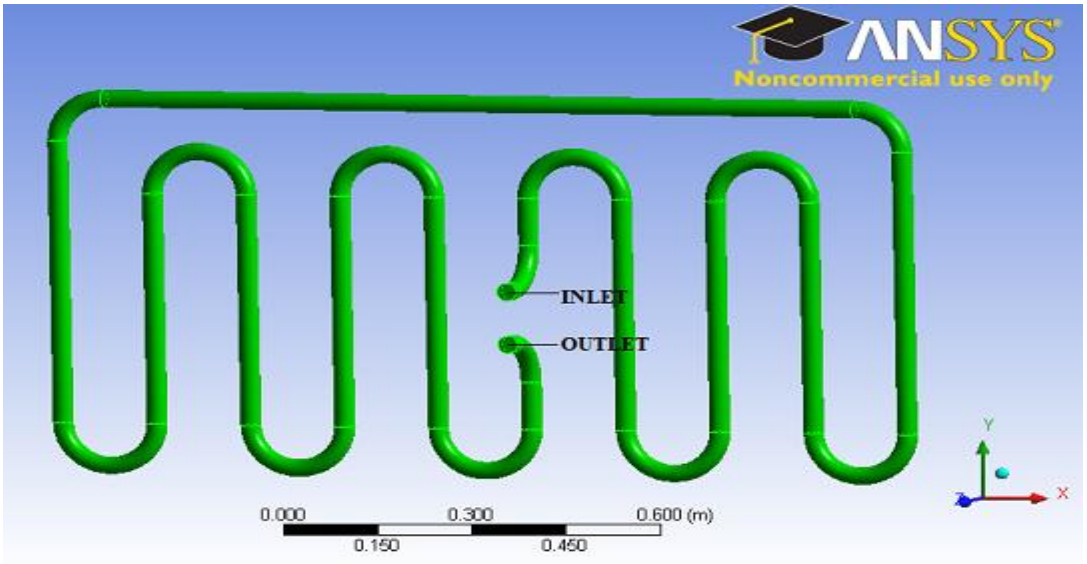

Figure 3.2 Cooling pipe of stave cooler

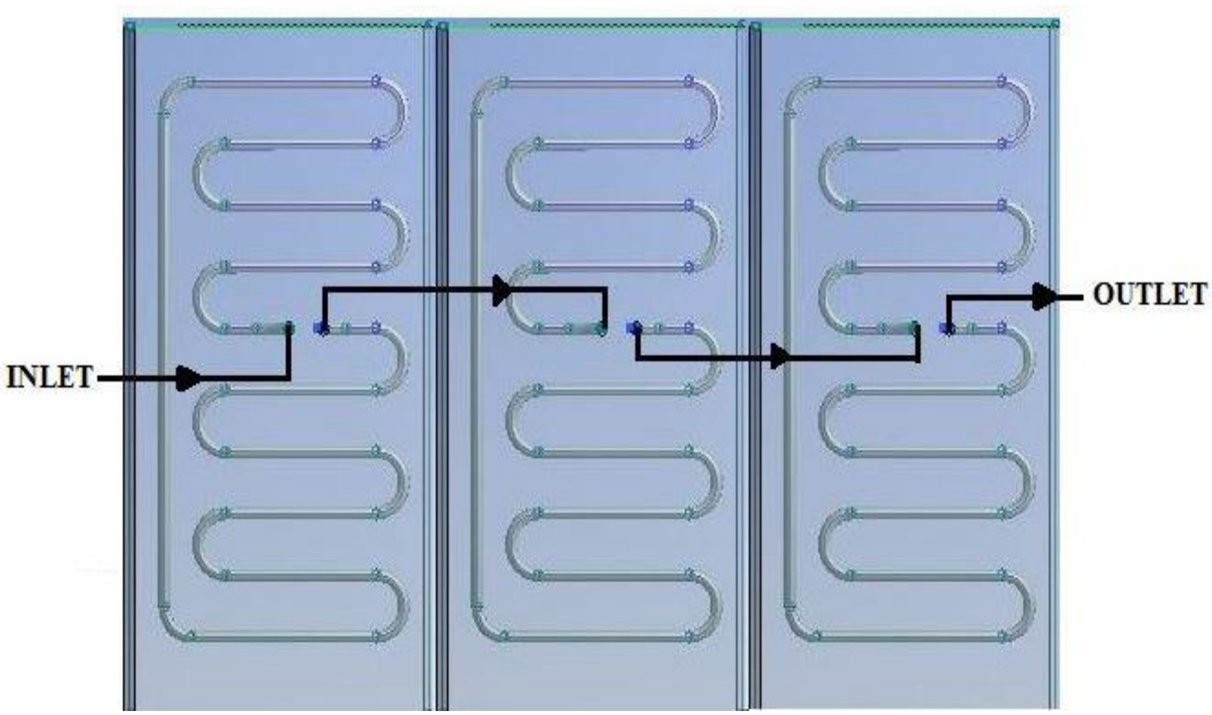

Figure 3.3 Stave cooler arrangement in Blast Furnace

Cooling Stave are arranged in a loop,which are connected in a series the above figure 3.3 shown how to connect two or more than two stave.In this figure one is inlet and another is outlet from inlet water is enter to the looping of three staves and from outlet water or nitrogen is comes out.then cooling fluid passed to the cooling tank after cooling again come to the inlet it means water is ciculate.

Table 3.1 Dimension of Stave Cooler

Part	Thickness	Width	Height
Stave Body	0.2m	0.9	1.640m

Table 3.2 Dimension of casting coil in a stave

Part	Diameter	Length
Casting coil	0.33m	8.420m

Table 3.3 Different metal used in stave cooler

Metal	K (w/mk)	ρ (kg/m3)	Cp (J/kgk)
Copper	387	8940	381
Cast Iron	42	7200	460

Fundamental equation for solving the fluid flow problem

1. Continuity Equation:

$$\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \qquad \text{equation 1}$$

This law applied to a fluid passing through an fixed control volume.

2. Navier-Stokes Equation:

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=\rho x-\frac{\partial p}{\partial x}+\frac{1}{3}\mu\frac{\partial}{\partial x}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)+\mu\nabla^2 u \qquad \text{equation 2}$$

Above equation 2 obtained from Newton's Law of Motion to a fluid element and is also called the momentum equation. It is used to model turbulent flow, where the fluid parameters are interpreted as time-averaged values.

$$\rho c_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=\left(u\frac{\partial p}{\partial x}+v\frac{\partial p}{\partial y}+w\frac{\partial p}{\partial z}\right)+k\nabla^2 T+\mu\phi \qquad \text{equation 3}$$

Where $\phi=2\left[\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial w}{\partial z}\right)^2\right]+\left[\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)^2+\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)^2+\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)^2\right]$

$$-\frac{2}{3}\left[\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right]^2$$

These above equation are used to solve the fluid flow problem using the finite volume method in a fluent, generally energy equation is used in this problem for finding the outer temperature of stave cooler.

CHAPTER 4

4 EXPERIMENTAL AND NUMRICAL ANLYSIS

This work about the modeling and numerical analysis of actual stave cooler used in Blast Furnace of Rourkela steel plant(RSP). It have identified a stave cooler for experimental base,which is subjected to maximun heat load in the furnace. A analytical model has been developed with the help of software taking over all dimension from plant data base.The model developed is identical to the actual stave cooler used in RSP. Practical data have taken from experimental setup based on the same identified stave cooler.From the experimental setup we measure the actual heat load in subjective stave cooler. When the same heat load calculated from experimental setup is put in analytical model in ANSYS then temperature difference (dT) Matched to be as in the actual setup.

4.1 Numerical Analysis

In this work a Three-dimensional numerical study has been undertaken to study the effects of inlet, outlet and wall temperature of casting hole in stave cooler. Heat flux has given to the one side of stave,which having one couple wall in between stave body and fluid body.This couple wall is created by make interface between solid wall and fluid wall. Mass flow rate of fluid has given to the Inlet.

The steps for simulation and analysis are:

1. After importing the .msh file
2. the first step is the material selection. The material is selected for the stave body i.e. cast iron,copper.
3. The materials selected for Fluid ie water or nitrogen
4. Then it has been given assumptions and boundary conditions to the stave cooler for the thermal calculations
5. Then it has been checked boundry condition of interface wall if couple wall come than it is correct.
6. Then it has given for iteration.

.

4.1.1 Assumption

1.Steady state conductive heat transfer process

2.Three Dimentional

4.1.2 Boundary conditions of stave cooler for thermal calculation

1. Wall of stave cooler assumed to be insulated except hot wall.
2. Heat flux has given on the hot wall of stave cooler.
3. Heat flux varied according to the position of Blast Furneace**.**
4. Cooling fluid entered at constant temperature i.e 300K.
5. Mass flow rate has given to the inlet.

4.2 Experimental study

In the experimental study setup we measure the actual heat load in subjective stave cooler. It is consists of two number of temperature measuring device filled to the inlet and outlet of subjective stave cooler.Flow rate of cooling fluid was measured by the volume flow meter,which is in installed in the inlet line of the stave cooler.Fluid pressure is measured by the pressure gauge,which is installed in the fluid flow line of cooling system. In Rourkela steel plant (RSP) we arranged of sufficient nitrogen supply near the subject stave cooler for experimental purposes.Wall surface temperature was measured by the thermocouple put in direct contact with the surface.we have done some experimental work with different stave cooler in the bosh and hearth zone of a blast furnace. We have setup the thermocouple in both the pipes inlet as well as outlet for measuring temperature,setup shown in below figure4.1.We have calculated the heat extracted by water at different zones.

Figure 4.1 Thermocouple arrangement in RSP

The data collected during the experiment were tabulated below the data of table 4.1 was used for calculate the heat extraction by the stave cooler in Bosh position of Blast Furnace in Plant and the data of Table 4.2 and 4.3 has taken from Hearth position and Lower Hearth Bottom(LBH) of Blast Furnace which are help to calculate the total heat extracted by the stave .All data got during Experiment in Rourkela steel Plant.

T**able 4.1**HeatExtracted measurement of stave Coolers Bosh position Raw I & II

Sl No	**Stave Cooler**	**Inlet ^{0}C**	**Outlet ^{0}C**	**TempDiff ^{0}C**	**Mass Flow Rate (Kg/s)**	**Heat Extracted (Watt)**	**Total Heat (Watt)**
1	1-1	27.4	32.8	5.4	0.55	12435.39	12435.39
2	2-2	27.4	30.8	3.4	0.468	6662.35	19097.74
3	3-3	24.4	30.8	6.4	0.625	13398.40	32496.14
4	4-4	24.4	35.6	11.2	0.652	29309	61805.1444
5	5-5	24.4	33.2	8.8	0.69	24023.33	85828.47
6	6-6	24.4	35.4	7	0.52	10223.21	106051.68
7	7-7	24.4	34	8.4	0.68	18288.816	124340.50

Table 4.2 Heat Measurment of Hearth cooler in RSP

Sl. No.	Stave Cooler	Inlet ^0C	Outlet ^0C	Temp Diff ^0C	Mass Flow rate Kg/s	Heat Extracted (Watt)	Total Heat (Watt)
1	1--2	24.2	27.2	3	0.71	8918.31	8918.31
2	3--4	23.6	25	1.4	0.9	5275.62	14193.93
3	5--6	23.6	24.4	0.8	1.153	3862.089	18056.02
4	7--8	23.6	24.2	0.6	1.0344	2598.62	20654.64
5	9--10	23.6	24.2	0.6	1.5	3768.3	24422.94
6	11--12	23.6	23.8	0.2	1.3	1088.62	25511.56
7	13--14	23.6	23.8	0.2	1.5	1256.1	26767.66

Table 4.3 Heat measurement of Hearth cooler (LHB) in RSP

Sl No	Stave Cooler	Inlet ^0C	Outlet ^0C	Temp Diff ^0C	Mass Flow rate (Kg/s)	Heat Extracted (Watt)	Total Heat (Watt)
1	1-2	23.2	26.2	3	0.18	2260.98	2260.98
2	3-4	21.8	24.6	2.8	1.3	15240.68	17501.66
3	5-6	21.8	23.6	1.8	1.2	9043.92	26545.58
4	7-8	21.8	24.2	2.4	1.2	12058.56	38604.14
5	9	21.8	23.2	1.4	1.5	8792.7	47396.84
6	10-11	21.8	24.4	2.6	1.07	11648.23	59045.07
7	12-13	21.8	24	2.2	1.2	11053.68	70098.75

4.3 Formula used for calculation

$$Q = -K \times A \times \frac{dT}{dx} \qquad \text{equation 4}$$

The above equation 4 is called as Foourier Laws of Heat conduction ,which was used to calculate total heat strike on a hot face of stave.Negtive sign indicate the decreasing temperature alongwith the direction of increasing thickness or the direction of heat flow

$$q = \frac{Q}{A} \qquad \text{equation 5}$$

Heat flux is define as the ratio of heat and surface area of body,equation 5 is used to calculate the heat flux on the hot surface of stave body.

$$Q = \dot{m} c_p dT \qquad \text{equation 6}$$

4.4 Summery of Exeperiments

Temperature difference between inlet and outlet of stave cooler have obtained from exeperimant by the help of Thermocouple,then total heat extract by the stave has calculated using the help of equation 6.This analysis is essential for save the life of stave cooler.

CHAPTER 5

5 RESULTS AND DISCUSSION

Results deals with the experimental graph and analytical graph and contour plots of themeparture made for the stave cooler. Actual heat flux calculated with the help of experiment,then heat flux is put in the 3-D model of stave after that it was found that temperature difference of numerical model stave cooler matched to the practically stave cooler of RSP blast furnace. this analysis has been done using two nitrogen and water. In experiment we have given same mass flow rate of water as well as nitrogen then it was found heat extacted by water cooling fluid was greater than nitrogen.when we passed a four times mass flow rate of nitrogen more than water mass flow rate then it was found that the heat extraction of water fluid and nitrogen is same.The value obtained by practically,which is exactly identical as in the numerical model. This analysis have done in using different type of material like as cooper, andcast iron then it found that copper is better then other material because of high thertmal conductivity.the graph and contour plots of temperature shown in below .

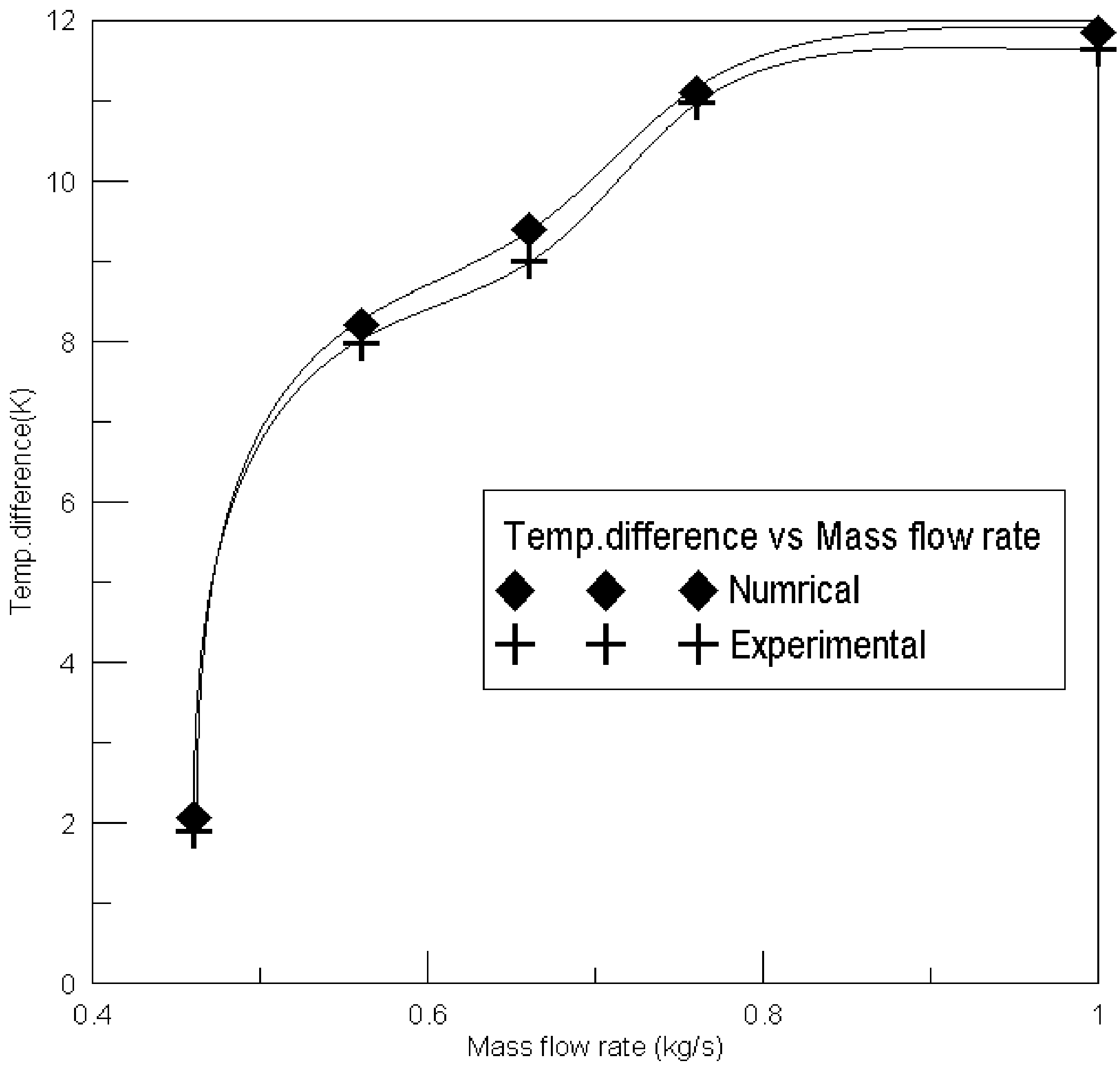

Figure 5.1 Compare between Experimental data and Numrical data

This above Fig.5.1 shows temperature difference of stave cooler from stack to belly position of Blast Furnace.Above graph shows experimental data(Exp.) is very closed to numerical data in this graph temperature is increase and some where decrease because of stave cooler arrengament and mass flow rate.

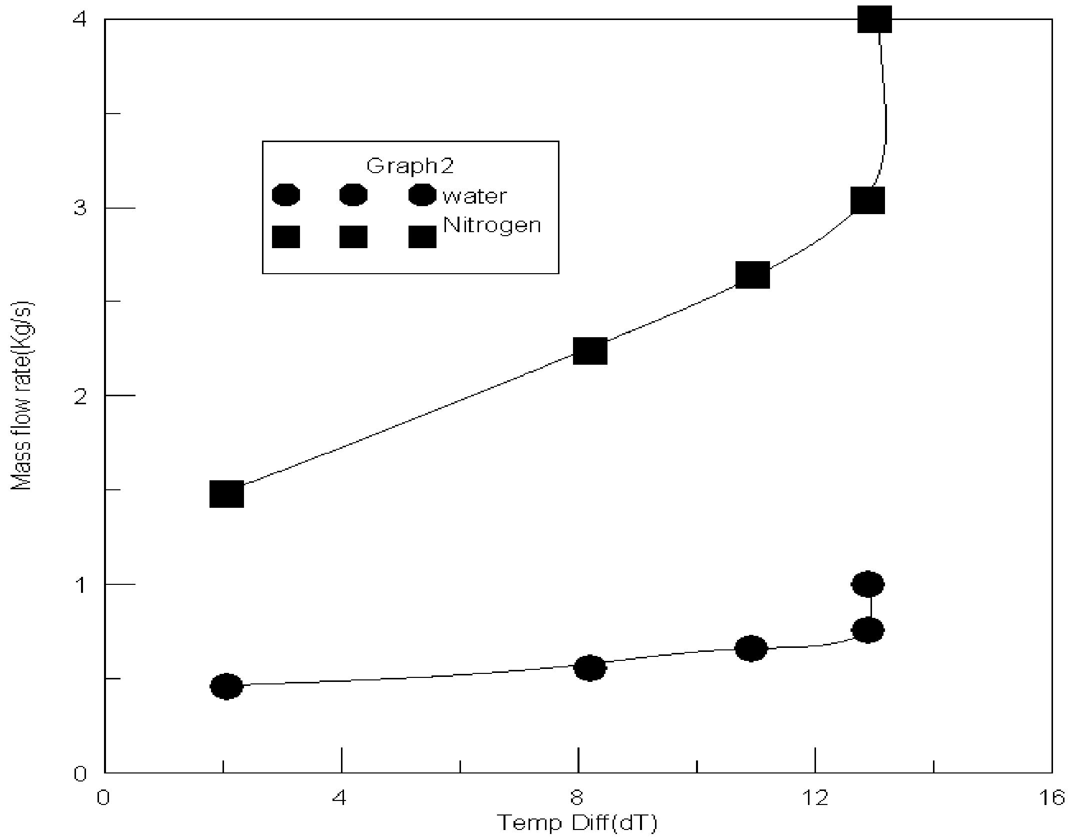

Figure 5.2 Compare Temprature difference(dT) between Nitrogen and Water

Above Figure5.2shows same temperature difference occure for both water and nitrogen. As the ratio of specific heat of nitrogen and water are in the range of 1:4, mass flow rate of nitrogen is increased four times than water in order to maintained the same heat transfetr rate in the stave cooler.

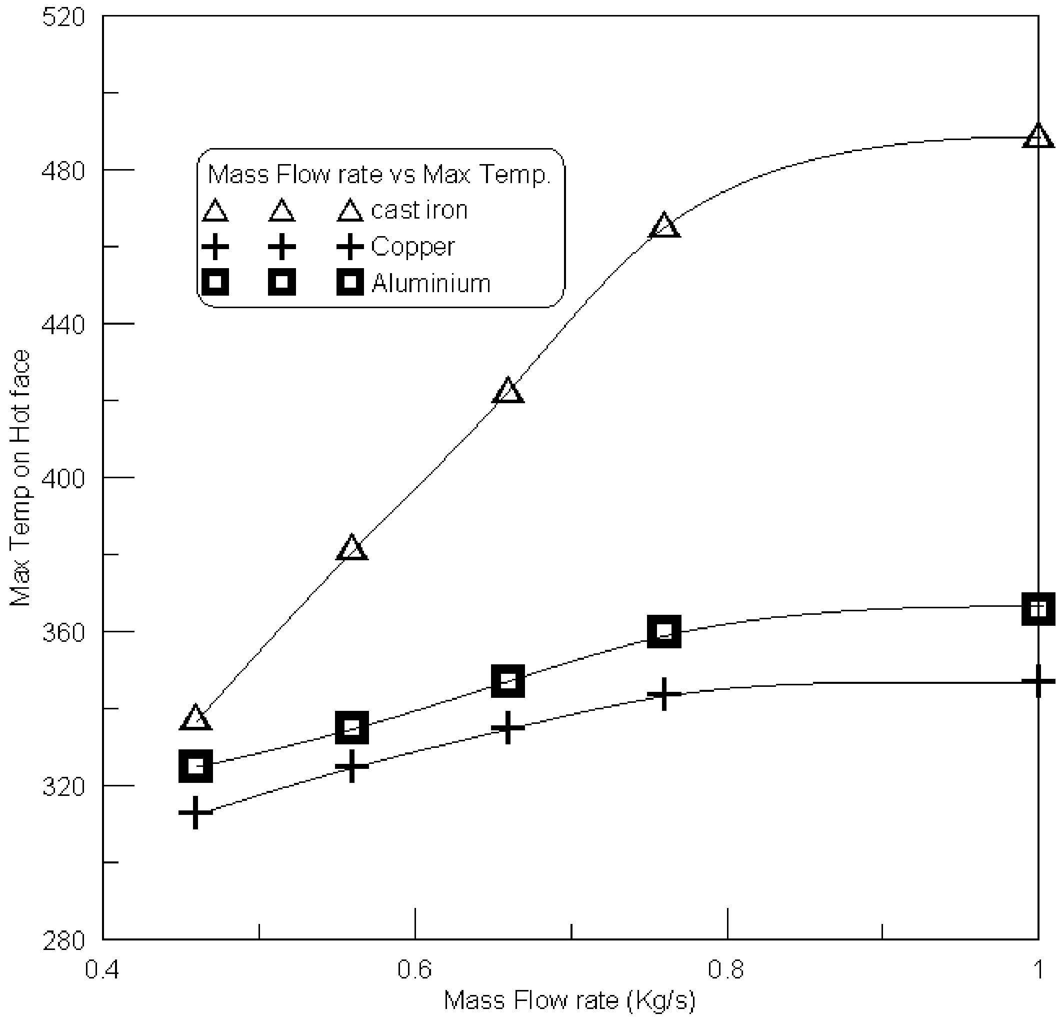

Figure 5.3 Compare maximum temperature between cast iron,copper and aluminium.

Above Fig.5.3shows hot surface temperature according to mass flow rate of different material i.e. cast iron,aluminium,copper it found that cast iron having more temperature on the hot surface of stave cooler due to thermal conductivity of material, copper have more thermal conductivity than other hence copper is better than other.

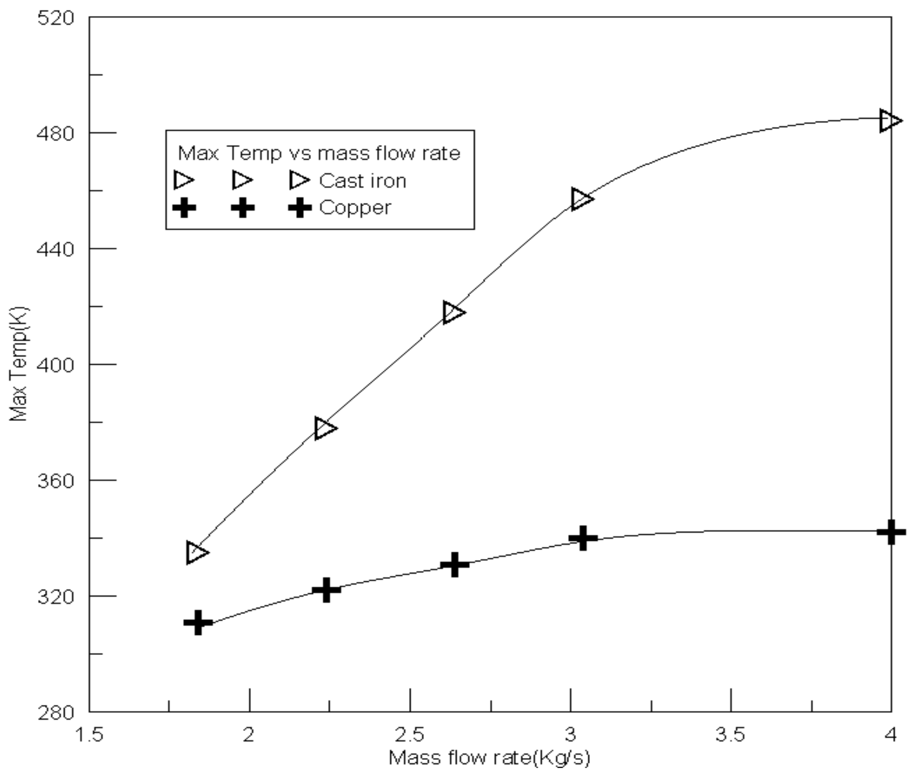

Figure 5.4 Compare maxium temperature between cast iron and copper using nitrogen

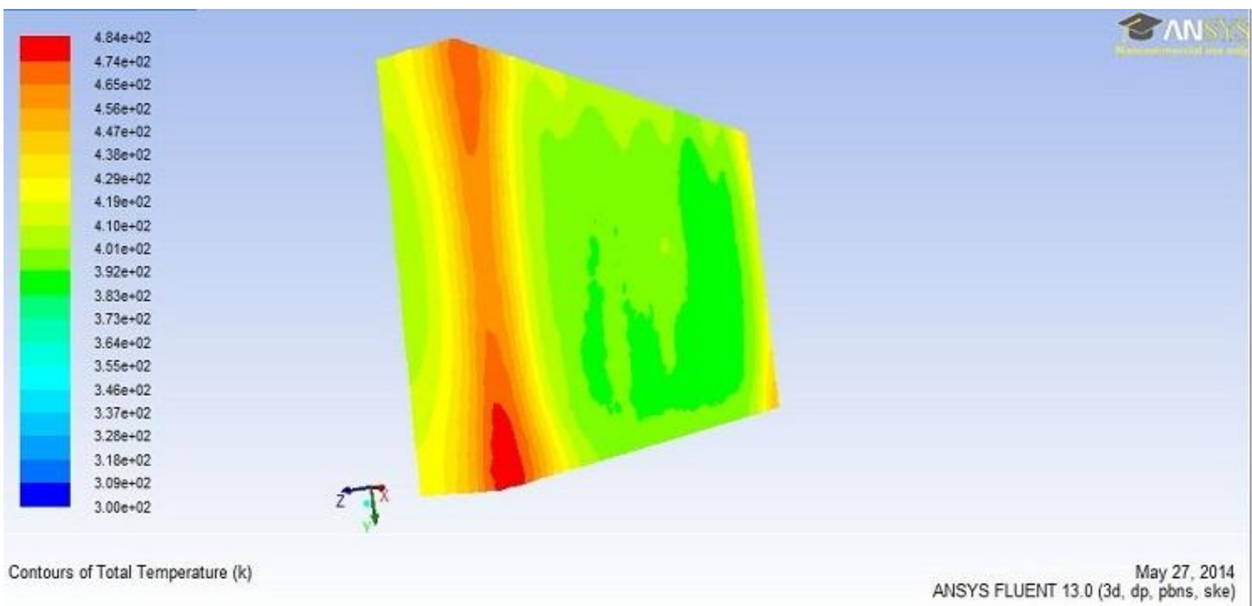

Figure 5.5 Temperature Contours of cast iron stave with nitrogen

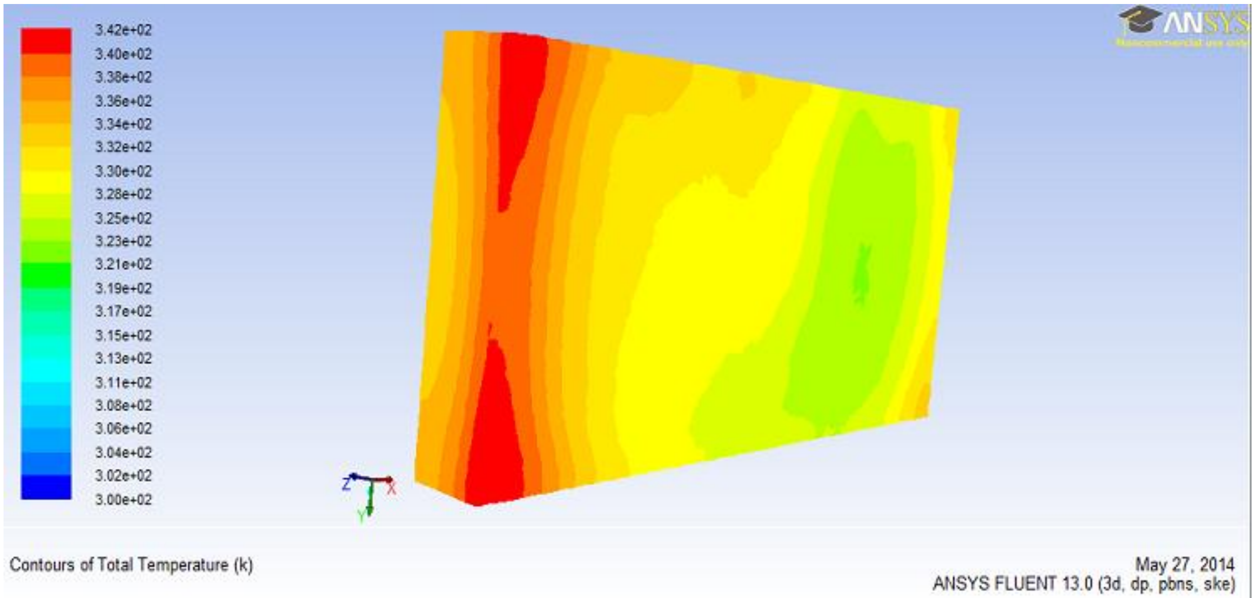

Figure 5.6 Temperature Contours of copper stave with nitrogen

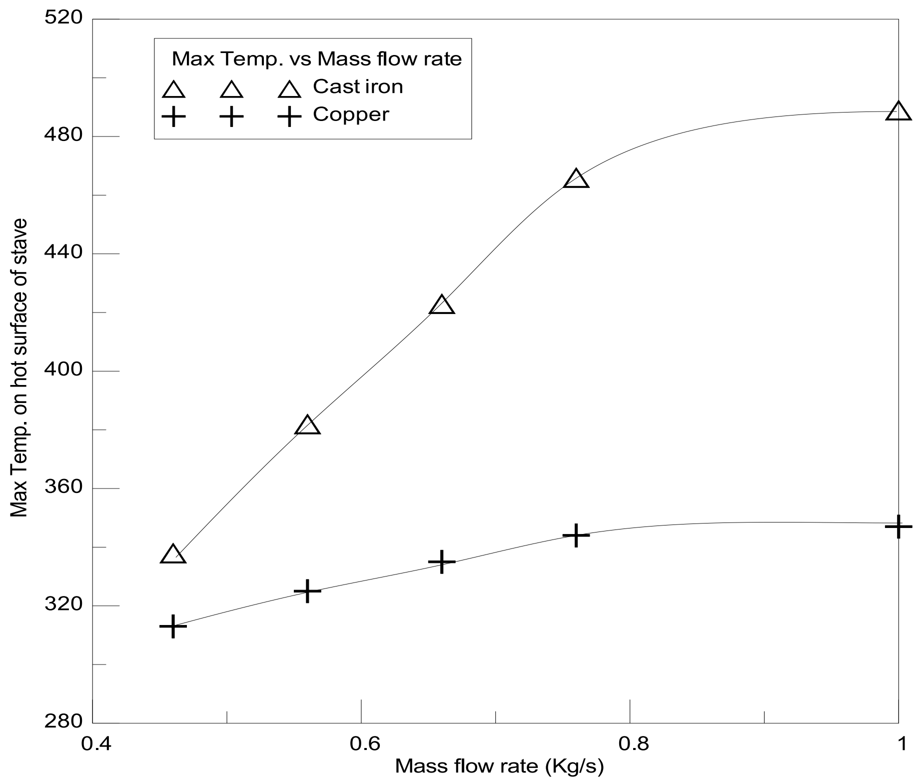

Figure 5.7 Compare maxium temperature between cast iron and copper using Water

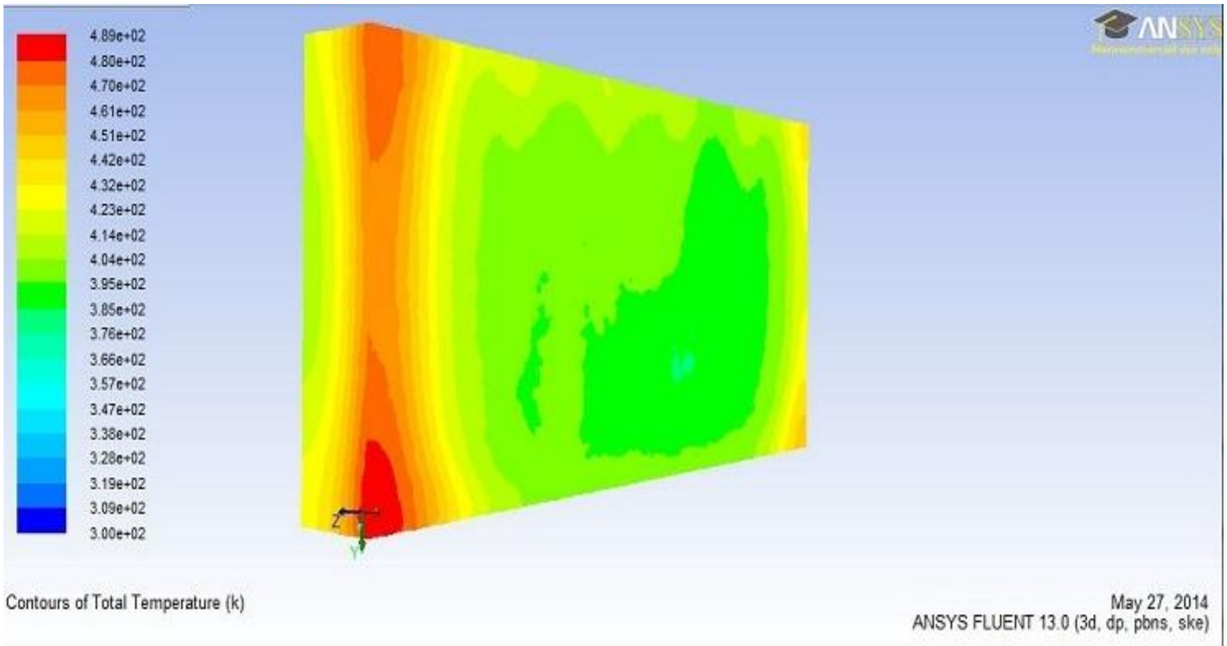

Figure 5.8 Temperature Contours of cast iron stave with water

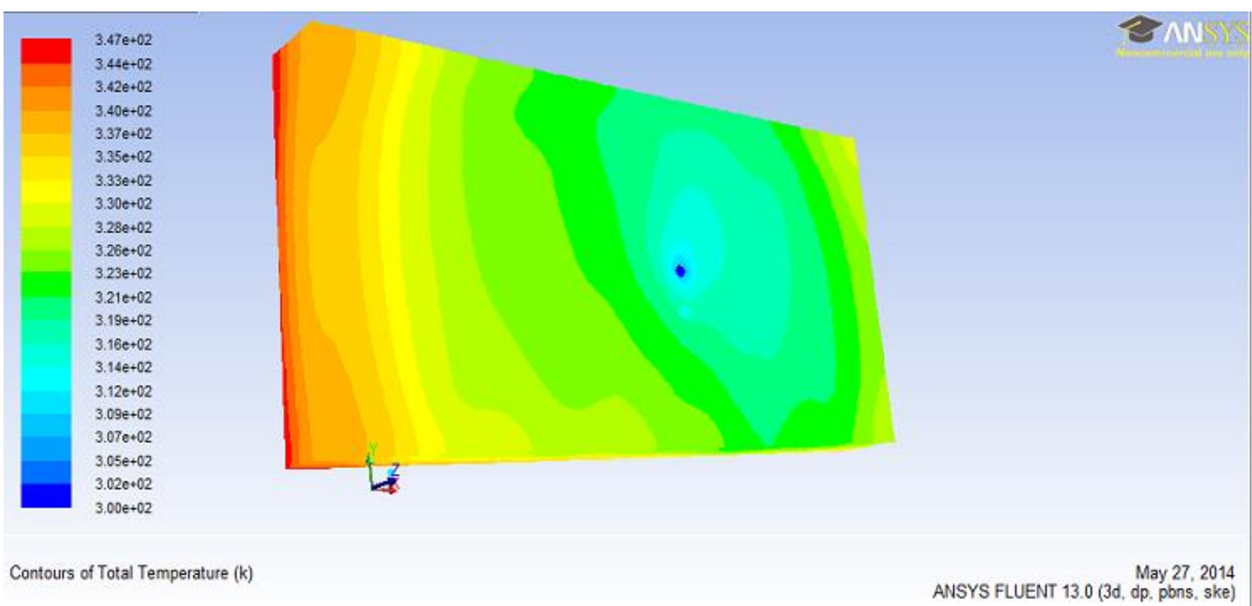

Figure 5.9 Temperature Contours of copper stave with water

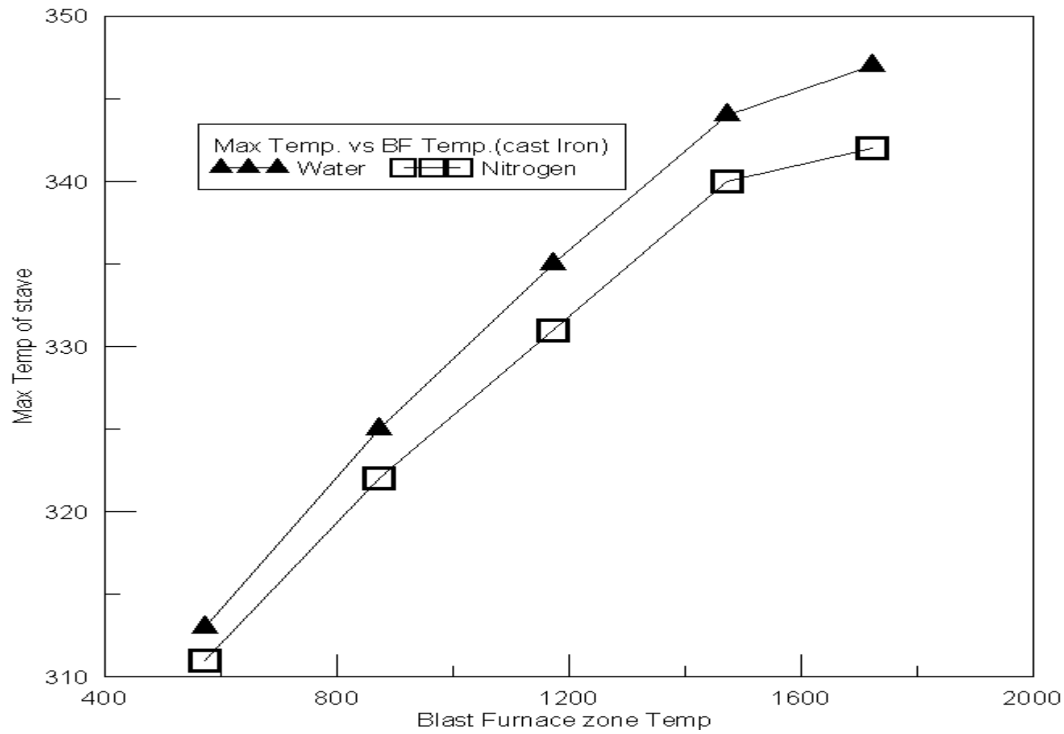

Figure 5.10 Graph shown Max temperature on cast iron stave at different zone of Blast Furnace

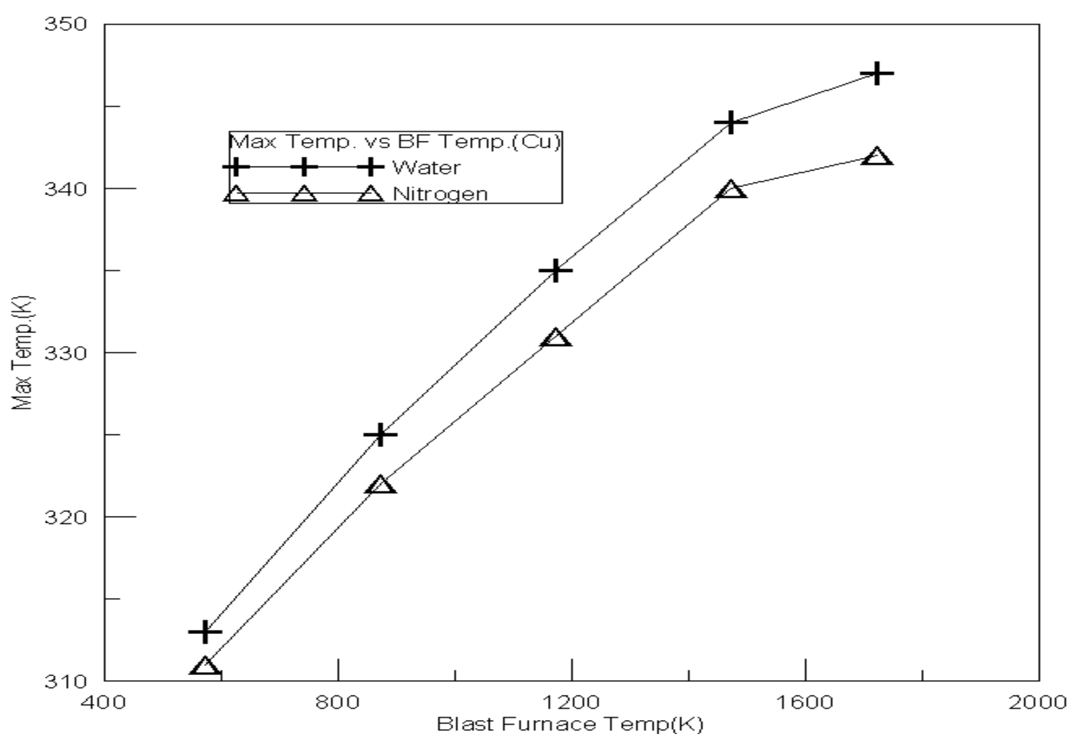

Figure 5.11 Graph shown Max temperature on copper stave at different zone of Blast Furnace

Fig.5.4 shows a variation of hot face temperature of cast iron stave and copper stave copper stave.when passed a water through both stave then it got a copper stave having minimum hot surfece temerature as compare to cast iron. In Fig.5.5 given same results to the Fig.5.4 but in this case cooling medium is nitrogen, cast iron stave show maximum hot surface temperature due to low thermal conductivity. Fig.5.10 and Fig.5.11 shows nitrogen is alternative cooling medium of stave cooler because when nitrogen is flowing through the cast iron stave and copper stave then hot face of stave shows minimum temperature.

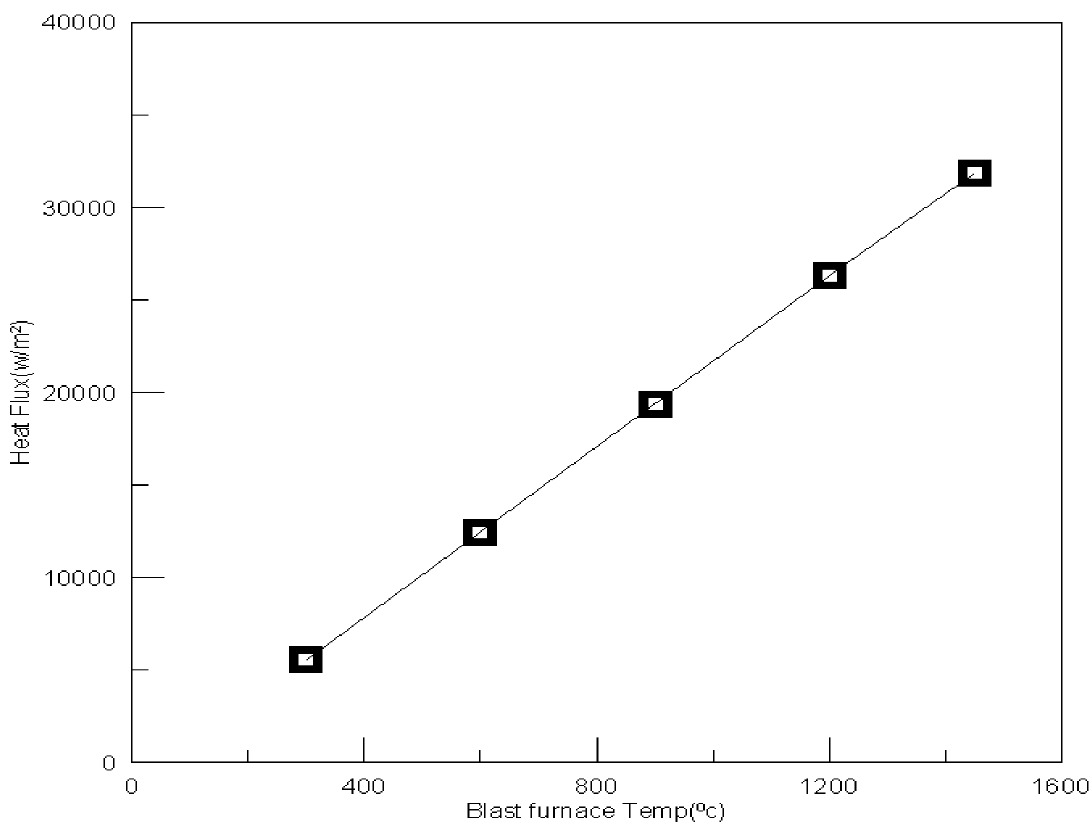

Figure 5. 12 Heat flux on the hot face of stave from stack to belly position of Blast Furnace**.**

Above Fig.5.12 shows heat fluxexperienced on hot surface of stave cooler from stack to belly position of Blast Furnace.

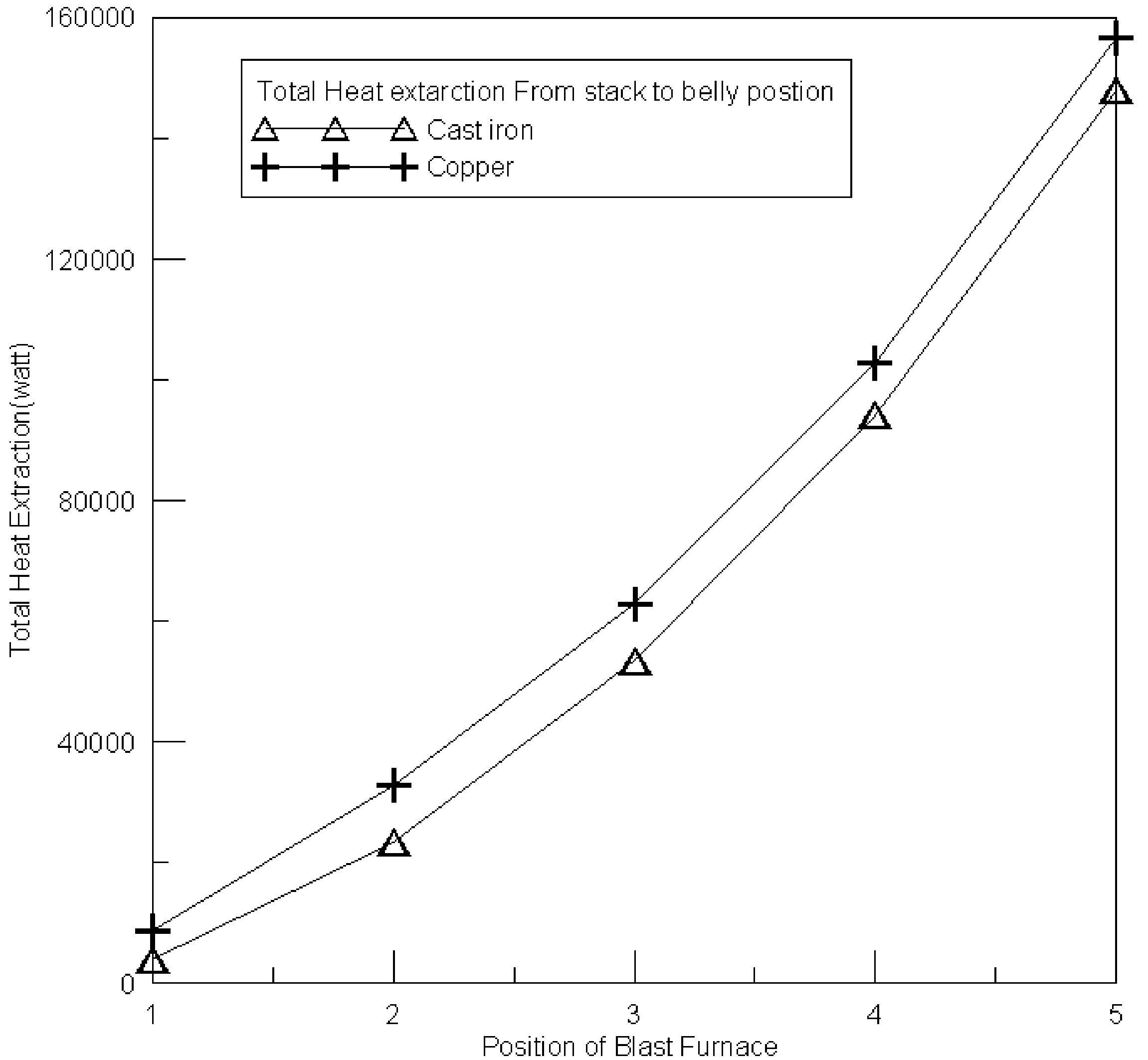

Figure 5. 13Total heat extraction from stack to belly position of Blast Furnace.

Above Fig.5.13 shows total heat extraction at different position from stack to belly position of Blast Furnace in this case copper extracted more heat than cast iron because of higher conductivity hence copper stave is better than other stave.

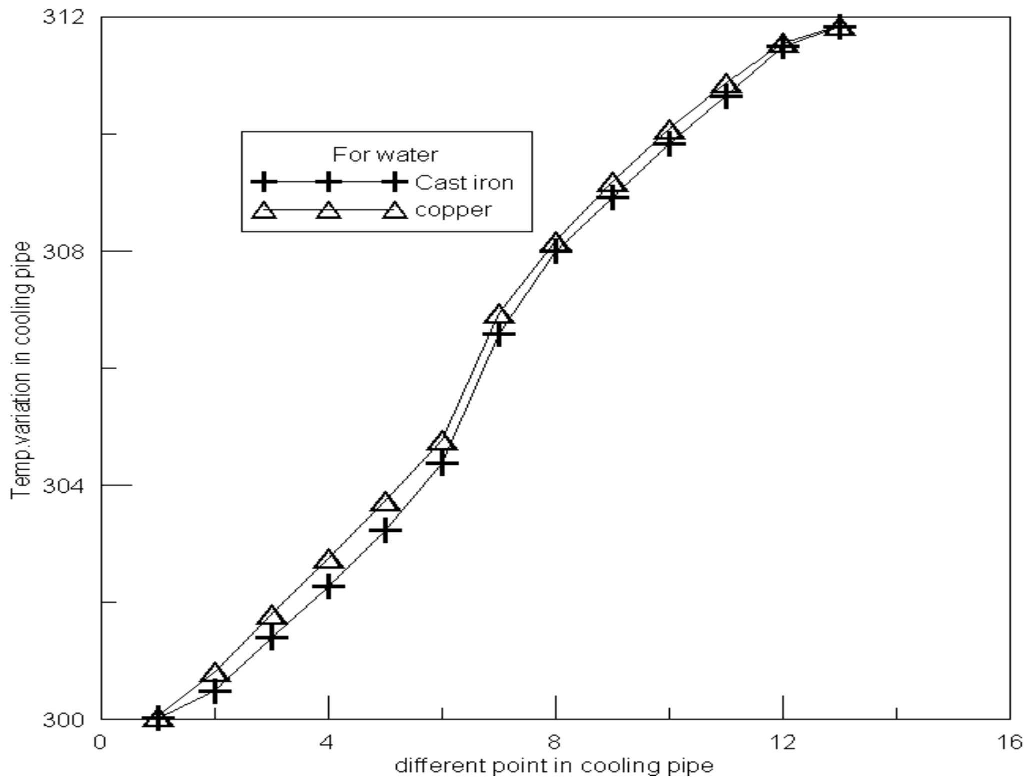

Figure 5.14 Temperature of water cooling pipe at a various point.

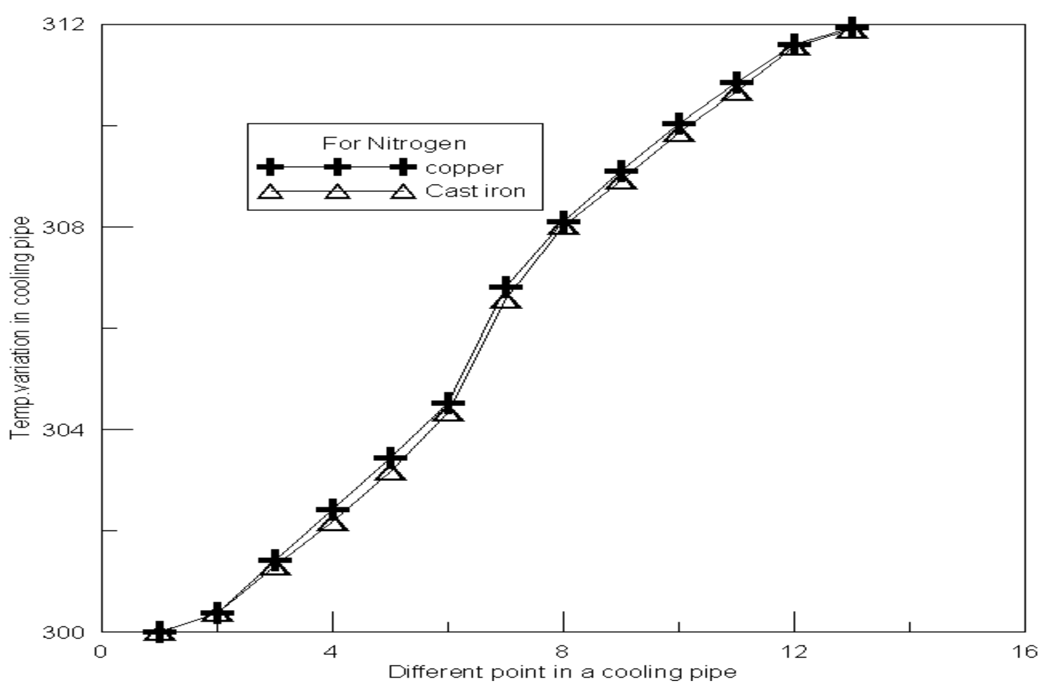

Figure 5.15 Temperature of nitrogen cooling pipe at a various point.

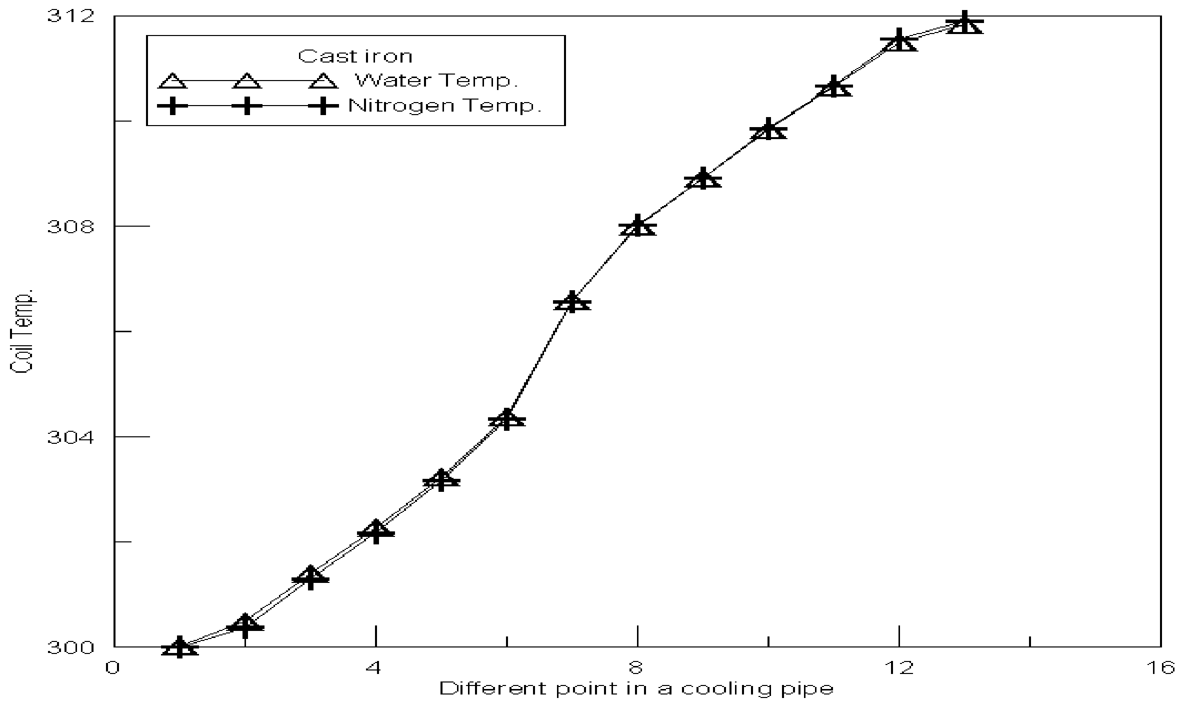

Figure 5.16 Temperature of nitrogen and water cooling pipe in cast iron stave

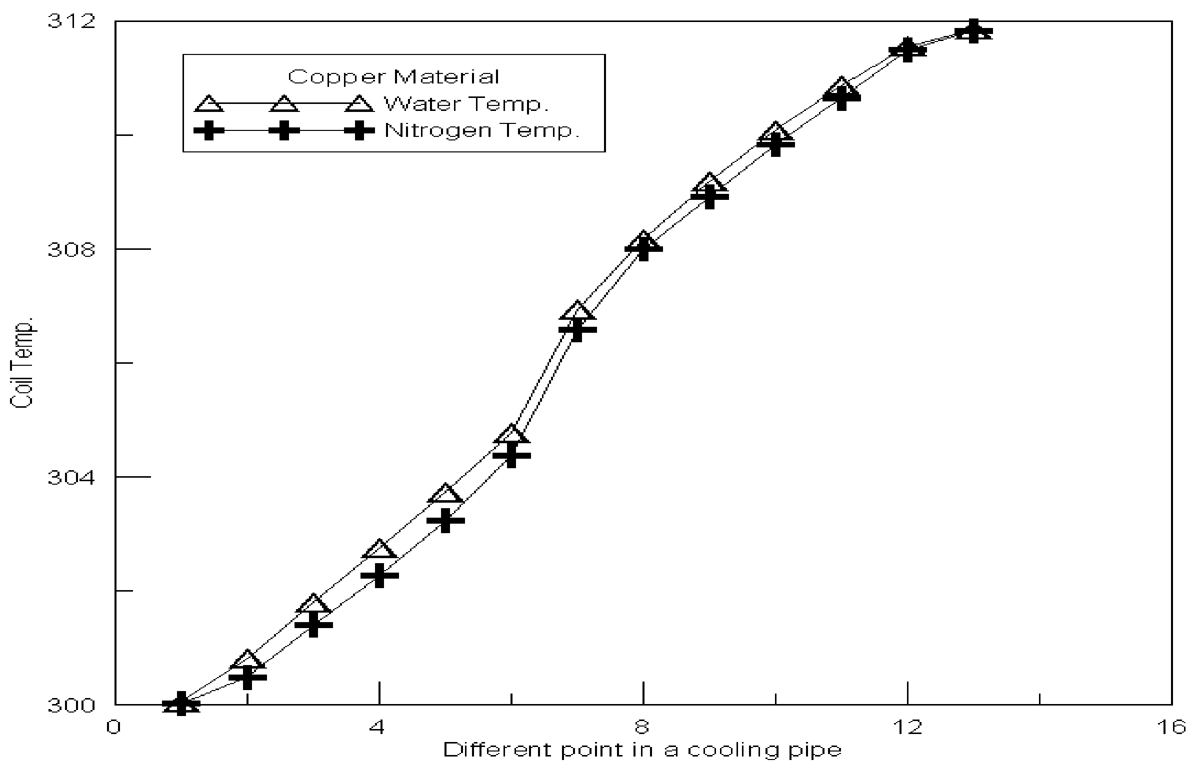

Figure 5.17 Temperature of nitrogen and water cooling pipe in a copper stave .

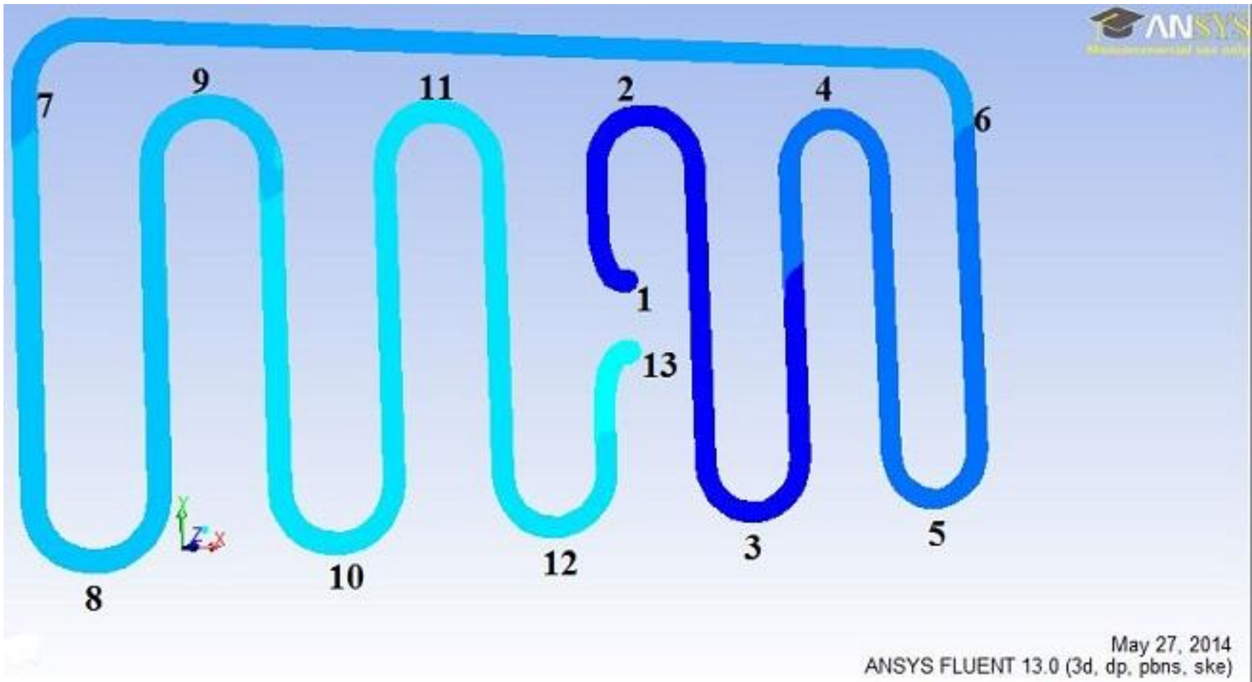

Figure 5.18 Temperature contours of cooling pipe

Fig.5.14,Fig.5.15, Fig.5.16 andFig.5.17 shows temperature in different position of cooling coil .In Fig.5.14 water has been passed through cast iron stave and copper stave then copper stave experienced some more temperature than cast iron stave because of thermal conductivity.In Fig.5.15 give same result to Fig.5.14 but cooling medium is different i.e.nitrogen.In Fig.5.16 and 5.17shows comprision between nitrogen and water in a different stave in both case found that nitrogen coil temperature has slightly decreased and some where same temperature.In Fig.5.18 there are 13 point 1 and 13 is indicate inlet and outlet respectively and point has taken for calculate the temperature of coil at different position.

CHAPTER 6

6 CONCLUSIONS

The overall conclusions of the present work. In modeling and proposed analysis methodology of the cooling stave, the main element is the tool by which simulation is to be done. So, WORKBENCH software is used for the modeling and ANSYS is used for analysis. The results will be achieved based on some parameters, assumptions, and boundary conditions. These all values has taken from Rourkela steel plant(RSP). Thus, the main aim of this study is to corroborated the nomrical model with experimental model of stave coolerandanalyze the behavior of stave cooler at different loads temperature from 573k to 1723 k through heat transfer analysis by finite element method software. S. In this study, three different types of materials like cast iron and copper and is considered for the stave cooler material of the blast furnace our work.Hence from the analysis it has been conclude that.

[1]. Numerical Data is corroborated with Expermental data.

[2]. Nitrogen can be a best alternative cooling medium of the Blast Furnace stave. As the ratio of specific heat of nitrogen and water are in the range of 1:4, mass flow rate of nitrogen is increased four times than water in order to maintened the same heat transfer rate in the stave cooler.

[3]. The copper stave is better than other stave.In copper stave maximum temperature on the hot face is lower than other stave,because copper material has higher thermal conductivity rather than cast iron,which is generally used in stave cooler.

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